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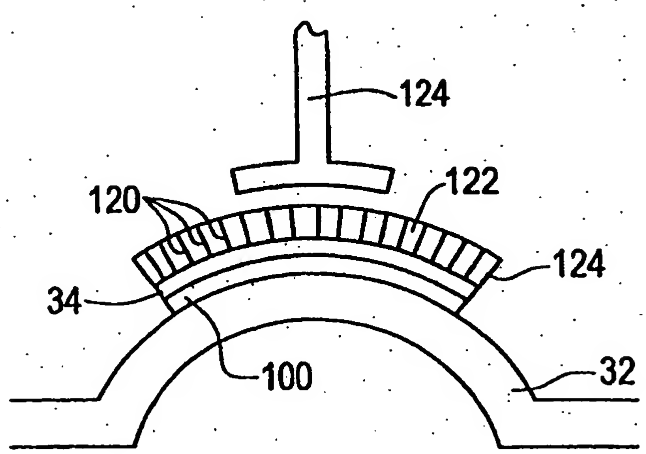
(54) Title: METHOD OF MANUFACTURING A PERFORATED LAMINATE

(57) Abstract

A method of making a perforated laminate (34), as shown in the Figure, wherein a laminate (34) to be perforated is placed on a lay-up tool (32); discrete, un-matted pins (120) are then driven through the laminate (34) to perforate it; and the pins (120) are then removed from the now perforated laminate (34).



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METHOD OF MANUFACTURING A PERFORATED LAMINATE

FIELD OF INVENTION

This invention relates to a method of manufacturing a perforated laminate useful, for example, as a part of a Helmholtz resonator structure.

BACKGROUND OF INVENTION

Perforated laminate sheets are used in a variety of application including Helmholtz resonators which include a honeycomb core supporting a perforated laminate face sheet. Such structures are used to form the arcuate inner surfaces of the nose cowl and thrust reverser components of a nacelle system of a commercial jet aircraft.

Surprisingly, perforating a composite laminate is not a straight forward process. The problems with drilling, abrasion, stamping, water jet, laser beam, and other similar processes are documented in U.S. Patent Nos. 5,268,055 and 5,252,279 incorporated herein by this reference.

So, these and other patents (e.g., 4,541,879; 4,390,584; 5,419,865; 4,612,737; and 4,486,372) delineate a different perforation methodology wherein a pin mat is used to perforate the composite laminate. The pin mat is formed from a plate with a number of interconnected, integral, upstanding pins or studs. A number of these pin mats are interlocked and a laminate, usually in the prepreg stage, is driven onto the pin mat using pressure or some kind of an impacting tool.

The primary limitation with this manufacturing method is the extremely high number of man hours required to fabricate the pin mats, assemble them on a forming tool, form the perforated composite laminate sheet, and to then re-work the perforations due to the fact that a number of pins usually break off from the pin mat during processing. Another limitation is that since the pins of the pin mat must be extracted from the perforated laminate in the same direction they were inserted, the pins must have a conical shape resulting in tapered perforations which are not as beneficial as straight perforations.

SUMMARY OF INVENTION

It is therefore an object of this invention to provide an improved method of manufacturing a perforated laminate.

It is a further object of this invention to provide such a method which dramatically reduces the number of man hours required to manufacture a perforate laminate.

It is a further object of this invention to provide such a method which requires little rework.

It is a further object of this invention to provide such a method which results in a higher quality perforated laminate.

It is a further object of this invention to provide such a method which results in a perforated laminate having perforations which are straight instead of tapered.

It is a further object of this invention to provide such a method which results in lower cost perforated laminate sheets useful in a variety of applications.

It is a further object of this invention to provide such a method which is easy to implement and simple to understand.

It is a further object of this invention to provide a perforated laminate sheet manufactured in accordance with the novel method of this invention.

This invention results from the realization that a higher quality and lower cost perforated laminate useful for Helmholtz resonator and other structures can be manufactured, not by using a pin mat and driving the laminate onto the pin mat, but instead by keeping the laminate stationary and then driving a number of discrete pins through the stationary laminate using discrete pins supported as they are driven into the laminate by, for example, a foam body which is much easier to manipulate and conform to the contours of the resulting laminate than the prior art pin mats which are difficult to manufacture in the first place and also difficult to work with. By using the discrete pins instead of the pin mats, straight shaft pins can be used resulting in better formed perforations. In addition, the pins are easier to remove from the perforated laminate as compared to the broken off truncated, conical shaped pins of the prior art pin mat based manufacturing methods. Since the pin mat itself is eliminated in this invention, the problems and high number of man-hours associated with fabricating and forming the pin mats and orienting them on the forming tool are eliminated.

This invention features a method of making a perforated laminate. The method comprises placing the laminate on a lay-up tool; driving a plurality of discrete, un-matted pins through the laminate to perforate the laminate; and removing the pins from the perforated laminate.

The laminate is preferably held stationary as the plurality of discrete pins are driven therethrough unlike the prior art which requires forcing the laminate onto a pin mat. The step of driving may include initially placing the plurality of discrete pins in a compressible body and then placing the compressible body/pin combination on the laminate. Further included may be the step of disposing a receiving material between the lay-up tool and the

laminate.

The step of driving usually includes using an oscillating, vibratory impacting device such as an ultrasonic horn. The laminate may be at least partially cured before the pins are removed and step of removing may also include using an oscillating, vibratory impacting device such as an ultrasonic horn to drive the pins out of the laminate. Alternatively, the step of removing includes pushing the pins flush with one surface of the laminate.

Each discrete pin has preferably at least one pointed tip and a straight, non-conical shaft. Each discrete pin may, however, have two pointed tips. One pointed tip is usually used when the pins are removed in the same direction that they entered the laminate. Two pointed tips are used when the pins are removed by driving them in the same direction they entered the laminate.

This invention also features a perforated sheet manufactured in accordance with the method described above. The method of making a perforated laminate in accordance with this invention also includes assembling a laminate to be perforated; perforating the laminate using a plurality of pins not associated with a pin mat; and removing the pins from the perforated laminate. Moreover, extruded pin mats, typically only available in 27" x 43" sheets, require heat treating and thermoforming before use.

DISCLOSURE OF PREFERRED EMBODIMENT

Other objects, features and advantages will occur to those skilled in the art from the following description of a preferred embodiment and the accompanying drawings, in which:

Fig. 1 is a partial view of an aircraft having a nacelle that utilizes sound attenuation structures having perforated laminates manufactured in accordance with the subject invention;

Fig. 2 is a partial cutaway perspective view of a portion of the nacelle shown in Fig. 1 and illustrates the typical arcuate acoustic structures which utilize a perforated laminate manufactured in accordance with the subject invention;

Fig. 3 is a sectional side view of a Helmholtz resonator sound attenuation structure incorporating a perforated laminate sheet in accordance with the subject invention;

Figs. 4A and 4B are flow charts depicting the primary manufacturing steps of the prior art methods of making a perforated laminate using pin mats;

Fig. 5 is a schematic view of a prior art pin mat;

Fig. 6 is a schematic end view of the pin mat shown in Fig. 5 placed on a layup tool in accordance with the prior art;

Fig. 7 is a schematic end view of a prior art manufacturing step wherein a prepreg laminate is driven onto a pin mat in accordance with the prior art;

Fig. 8 is a graphical depiction comparing the total number of man hours required to manufacture a perforated laminate using the prior art methods to the method of the present invention;

Fig. 9 is a graphical depiction comparing the number of rework man hours using the prior art pin mat manufacturing based methods to the method of the subject invention;

Fig. 10 is a flow chart showing the primary manufacturing steps in accordance with the subject invention;

Fig. 11 is a schematic end view of the receiving material used in accordance with the method of the subject invention in place on a lay-up tool;

Fig. 12 is a more detailed flow chart of the pin insertion manufacturing steps of the method of this invention;

Fig. 13 is a schematic end view of the primary components used in the pin insertion steps of this invention in accordance with the flow chart of Figs. 12;

Fig. 14 is a schematic view depicting the primary steps involved in removing the pins from a partially or completely cured perforated laminate in accordance with the subject invention;

Fig. 15 is a schematic view showing the primary steps involved in an alternative way of removing the pins from a partially or completely cured perforated laminate in accordance with the subject invention;

Fig. 16 is a schematic view of one discrete pin used in the method of the subject invention;

Fig. 17 is a schematic view of another type of discrete pin useful in accordance with the method of this invention;

Fig. 18 is a view of a prior art pin of a pin mat in accordance with the prior art;

Fig. 19 is a schematic sectional view showing the details of the improved square hole perforation achievable in accordance with the method of this invention;

Fig. 20 is a schematic sectional view of a prior art conical shaped hole formed by using a pin mat; and

Fig. 21 is a schematic sectional view of a prior art perforation made in accordance with drilling or blasting operations.

As discussed in the background of the invention above, perforated laminate sheets are useful as parts of acoustic structures, for example, panels of nacelle 10, Fig. 1 of a

commercial jet aircraft. The arcuate inner surface 12, Fig. 2, of nose cowl 14 and the arcuate inner surface 15 of thrust reverser 16, for example, are formed of acoustic structure 20, Fig. 3 which includes perforated laminate sheet 34 supported by honeycomb core 22. Such a structure is often referred to as a Helmholtz resonator.

The prior art method of manufacturing perforated sheet 34, Fig. 3, is shown in Figs. 4-7. Pin mat 30, Fig. 5 is fabricated and then preshrunk and stress relieved, step 40, Fig. 4A. Next, pin mat 30 is ultrasonically trimmed, step 42 and the pins are then shaved from the pin mandrels, step 44. This structure is then contoured by oven forming, step 46. Curing tool 32, Fig. 6, is then cleaned and prepared, step 48, Fig. 4A and the pin mandrels are placed on the curing tool, step 50 as shown in Fig. 6. The shaved areas are touched up, step 52, and the gaps between adjacent mandrels are filled, step 54. Prepreg layer 34′, Fig. 7, which will eventually become perforated layer 34, Fig. 3, is then placed on pin mandrel 30, Fig. 7, step 56, Fig. 4B. This assembly is then bagged and perforated. This structure is then re-bagged to cure perforated prepreg 34′, step 62, Fig. 4B, in an autoclave, step 64. The combination of cured, perforated prepreg layer 34 and pin mat 30 is then removed from forming tool 32, Fig. 7, step 66, Fig. 4B. The pin mats 30, Fig. 7, are then removed from the cured perforated pre-form 34′, step 68, Fig. 4B.

At this stage, a serious amount of re-work is required, step 70. Many pins, broken off pin mat 30, Fig. 7, will reside in the perforations of the perforated sheet and these broken pins must be removed. In addition, a number of the perforations must be re-drilled.

The above process is currently carried out in order to make the perforated sheets for the inner linings of nacelle structures. Re-work step 70, Fig. 4B alone can require many man hours and the total man hours from step 40, Fig. 4A through step 70, Fig. 4B, can be excessive. See Figs. 8 and 9.

In the subject invention, however, the pin mats are eliminated and thus the total number of man hours is dramatically reduced. In addition, almost no re-work is required. First, receiving material 100, Fig. 11, is placed on lay-up forming tool 32, step 102, Fig. 10. Receiving material 100, Fig. 11, may, for example, be a layer of foam. The prepreg layer which will ultimately become the perforated sheet is then placed over receiving material 100, step 104, Fig. 6 and held stationary thereon. See also Fig 13. A set of discrete pins are then driven through the prepreg layer and into receiving material 100, step 106, Fig. 10, as discussed in more detail with reference to Fig. 13. A silicone layer is then placed on the pins and the structure is placed in an autoclave to stage, or completely cure the now perforated prepreg in an autoclave bag, step 108, Fig. 10. Finally, the discrete pins are

removed, step 110 as discussed in more detail with reference to Figs. 14 and 15.

One method of inserting the pins through the prepreg layer and into the receiving material, step 106, Fig. 10, is discussed with reference to Figs. 12 and 13. In step 150, Fig. 12, a plurality of discrete pins 120 are initially inserted into a compressible body, for example foam layer 122, Fig. 13 forming foam layer/pin combination 124. Foam layer/pin combination 124 is then placed on prepreg layer 34, Fig. 13, step 152, Fig. 12. Ultrasonic horn 124, Fig. 13 is then used to ultrasonically drive pins 120 through prepreg layer 34 and into receiving layer 100, step 154, Fig. 12. Other oscillating, vibratory impacting devices may also be used to drive pins 120 into the laminate to perforate it. See, e.g., U.S. Patent No. 5,268,055.

In an alternative embodiment, pins 120 are driven directly through prepreg layer 34 and into receiving layer 100 using, for example, an numerical control machine.

In any case, once these pins are driven through the prepreg layer 34 and into receiving layer 100, and after the prepreg layer is staged or cured, step 108, Fig. 10, the pins must be removed in accordance with the processing steps shown in Figs. 14 and 15.

In one example pins 120, Fig. 14 which have been previously inserted through laminate 34 into foam receptor layer 100 and after laminate 34 is then cured, are removed by driving them flush with laminate 34 and further into foam receptor layer 100 which rests on tool 167 using vibrating horn 124. Taper 211 on pins 120 permits easy removal of the laminate from the pins once the pins are driven flush.

In another example, laminate 34, Fig. 15 and foam receptor layer 100 have been removed from the curing tool and inverted. Foam 100 is then peeled away exposing the pointed ends of pins 120. Vibrating horn 124 is then used to drive pins 120 flush with the laminate. Taper 204, which previously aided insertion of the pins, is now used to aid their release from the laminate once they are driven flush. The pins either fall out in the direction shown by arrow 121 or they can be easily pulled out of laminate 34.

The result of using this method is a dramatic decrease (more than 30%) in the total number of man hours and hence the expense of manufacturing acoustic panels. In accordance with the prior art, re-work step 70, Fig. 4B, alone took many hours. In accordance with the subject invention, however, re-work, if any, is minimal as shown in Fig. 9. One reason for the reduction in the number of man hours when the method of this invention is used is the elimination of the pin mats which must be fabricated, formed, trimmed, and then assembled on a forming tool.

In addition, the manufacturing process of the subject invention produces higher

quality laminated perforated sheets to be used in acoustic panels. The discrete pins 120, Fig. 9, used are straight along the majority of their shaft length as shown at 200, Fig. 16, and 202, Fig. 17. In the example shown in Fig. 16, the pins are sharpened to a point 204 with one angled face 206, while for the pin shown in Fig. 17, the pins are sharpened to a point 208 with two angled faces 210 and 212. Point 211 is formed in a similar fashion to aid in removing the pin after it is driven into the laminate. The result is perforated sheet 214, Fig. 19 with perforation 216 having sharp corners 218, 220, 222, and 224. These sharp corners are preferred because of their sound attenuation characteristics.

In contrast, using prior art pin mat 30, Fig. 5 with interconnected tapered conical shaped pins such as the pin shown at 230, Fig. 18, a tapered perforation is formed as shown at 232, Fig. 20 in perforated sheet 235. This tapered perforation exhibits less than desirable sound attenuation qualities.

Other prior art methods of forming perforations including sand blasting and laser drilling to form the perforations such as perforation 234, Fig. 21 having rounded sides 236 and 238 which also exhibit poor sound attenuation characteristics.

Thus, the method of this invention provides a higher quality perforated laminate, severely reduces the number of man hours required to manufacture a perforate laminate, involves almost no rework, results in lower cost perforated laminate sheets useful in a variety of applications, and is easy to implement and simple to understand.

With this invention, a higher quality and lower cost perforated laminate useful for Helmholtz resonator and other structures is manufactured, not by using a pin mat and driving the laminate onto the pin mat in accordance with the prior art, but instead by keeping the laminate stationary on lay-up tool 32, Fig. 13 and then driving a number of discrete pins through the stationary laminate. The discrete pins may be supported as they are driven into the laminate by, for example, foam body 122 which is much easier to manipulate and conform to the contours of the resulting laminate and the forming tool as compared to prior rigid art pin mat 30, Fig. 5 which is difficult to manufacture in the first place and also difficult to work with. By using discrete pins 120, Fig. 13 instead of pin mat 30, Fig. 5, non-conical shaped pins can be used and the pins are easier to remove from the perforated laminate as compared to the broken off conical pins of the prior art pin mat based manufacturing methods. And, the shape of the resulting perforations (see, e.g., Fig. 19) is improved since the discrete pins used in accordance with the manufacturing method of this invention are not constrained to be of a conical shape.

Because the pins used in accordance with this invention are discrete and integrated

and not part of a pin mat, the steps of manufacturing the pin mats, forming the pin mandrels, orienting the pin mandrels on the forming tool, and removing the broken pins from the laminate of the prior art are eliminated (e.g. steps 40-54, Fig 4A and steps 66-70, Fig. 4B). This improvement alone saves hundreds of man hours. See Figs. 8 and 9. For an example of the complexity of forming and assembling the pin mat mandrels of the prior art see U.S. Patent No. 5,252,279, col. 8, line 3- col. 9, line 7. Conformable foam body 122, Fig. 13 is much easier to work with and thus results in a dramatic cost savings over prior art pin mat based methods.

In this invention the composition of foam body 124, pins 120, Fig. 13 and the operation of steps 150-154, Fig. 12 are set forth in U.S. Patent No. 5,589,015 incorporated herein by this reference. Receiving layer 100, Fig. 11 may be the same material as foam body 124. See also U.S. Patent No. 4,808,461; 5,466,506, and U.S. Application No. 08/545,392 filed October 19, 1995 (now allowed) also incorporated herein by this reference.

Although specific features of this invention are shown in some drawings and not others, this is for convenience only as each feature may be combined with any or all of the other features in accordance with the invention.

Other embodiments will occur to those skilled in the art and are within the following claims:

What is claimed is:

CLAIMS

1. A method of making a perforated laminate, the method comprising:

placing the laminate on a lay-up tool;

driving a plurality of discrete, un-matted pins

through the laminate to perforate the laminate; and

removing the pins from the perforated laminate.

2. The method of claim 1 in which the laminate is held stationary as the plurality of discrete pins are driven therethrough.

3. The method of claim 1 in which the step of driving includes initially placing the plurality of discrete pins in a compressible body and then placing the compressible body/pin combination on the laminate.

4. The method of claim 1 further including the step of disposing a receiving material between the lay-up tool and the laminate.

5. The method of claim 1 in which driving includes using an oscillating, vibratory impacting device.

6. The method of claim 5 in which said device is an ultrasonic horn.

7. The method of claim 1 further including at least partially curing the laminate before the pins are removed.

8. The method of claim 1 in which the step of removing includes using an oscillating, vibratory impacting device to drive the pins out of the laminate.

9. The method of claim 8 in which said device is an ultrasonic horn.

10. The method of claim 1 in which the step of removing includes pushing the pins flush with one surface of the laminate.

11. The method of claim 1 in which each discrete pin has a pointed tip and a straight, non-conical shaft.

12. The method of claim 11 in which each discrete pin has two pointed tips.

13. A perforated sheet manufactured in accordance with claim 1.

14. A method of making a perforated laminate, the method comprising:

assembling a laminate to be perforated;

perforating the laminate using a plurality of pins not associated with a pin mat; and

removing the pins from the perforated laminate.

15. A perforated laminate manufactured in accordance with the method of claim 14.

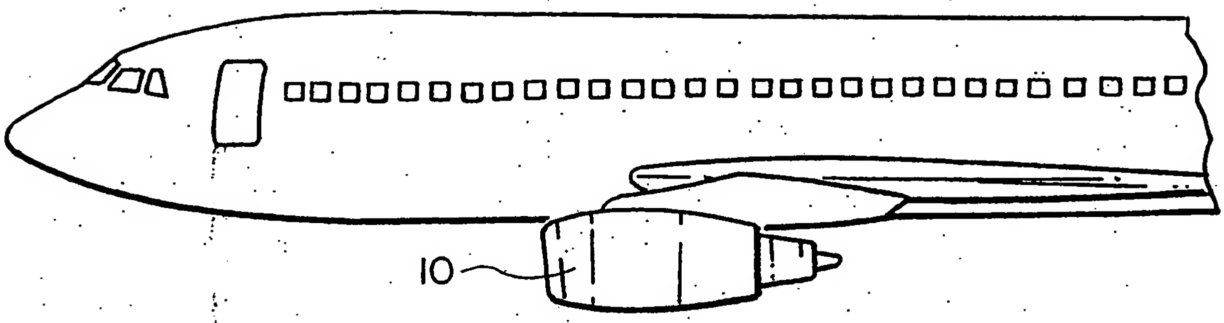

FIG. 1

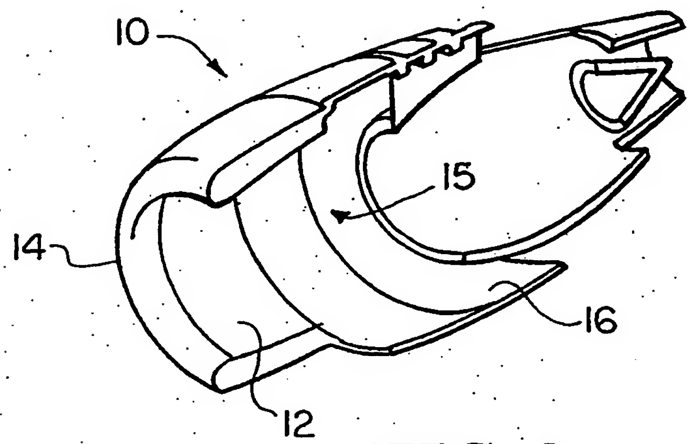

FIG. 2

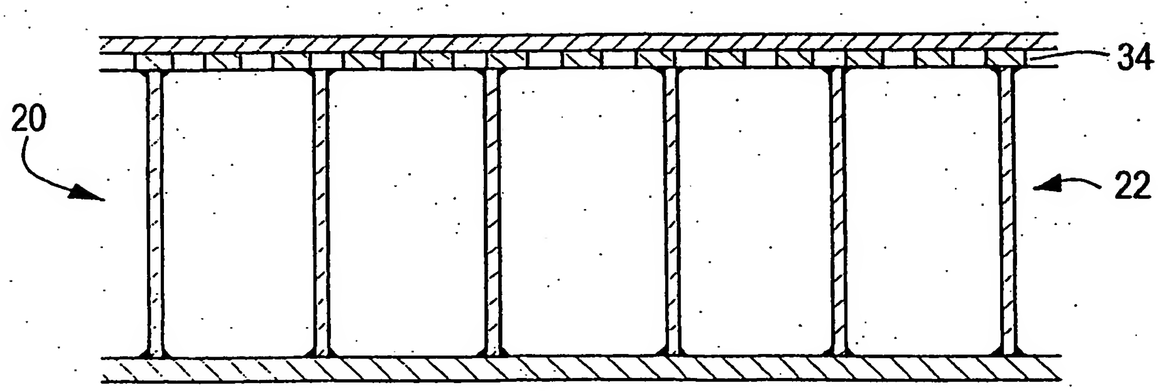

FIG. 3

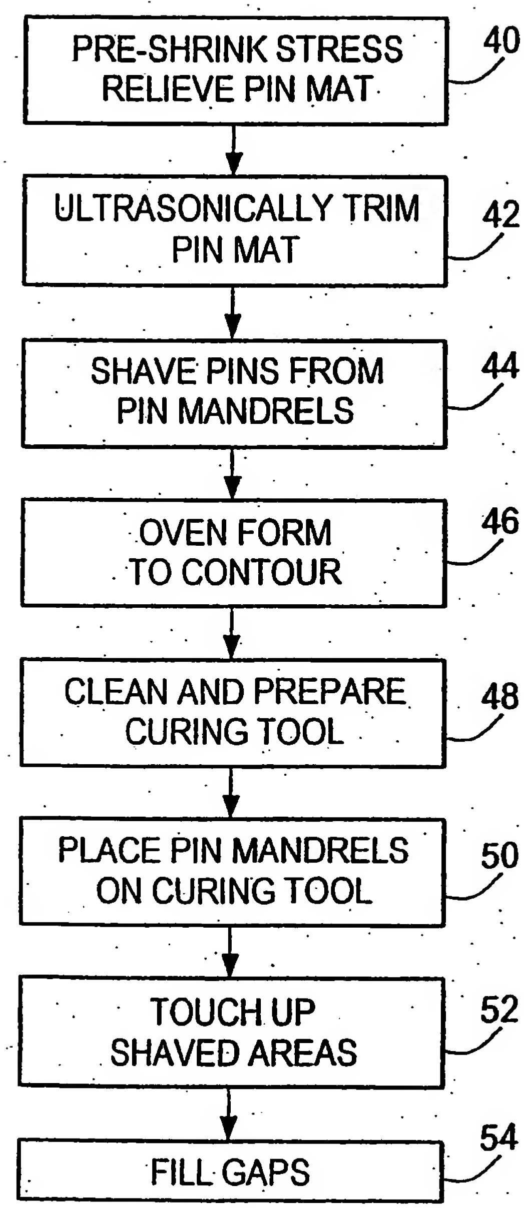

FIG. 4A
PRIOR ART

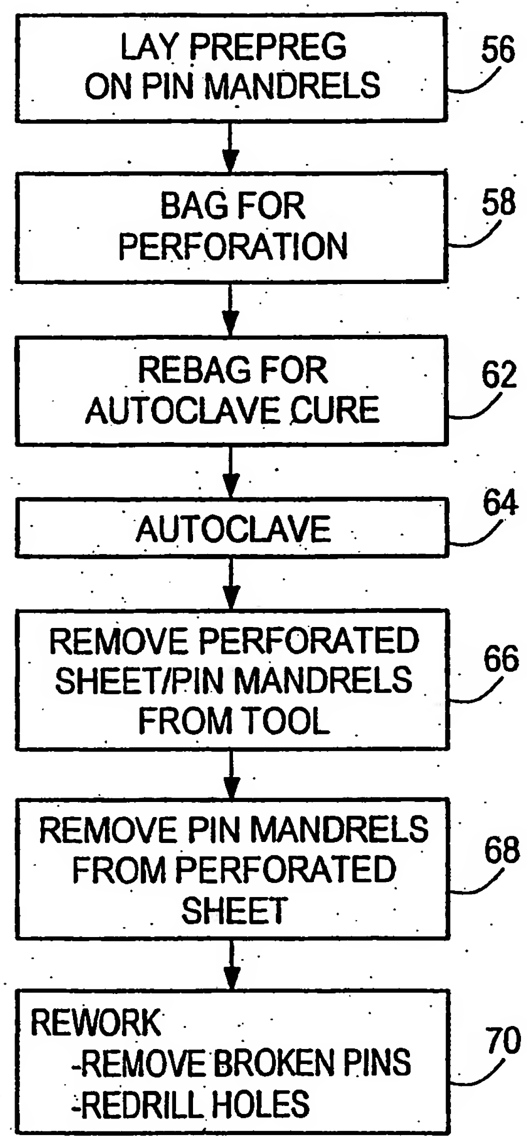

FIG. 4B
PRIOR ART

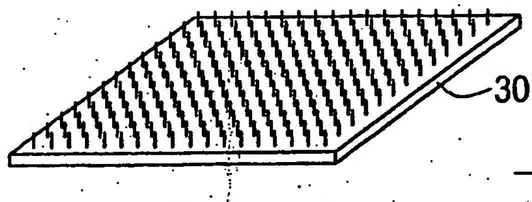

FIG. 5
PRIOR ART

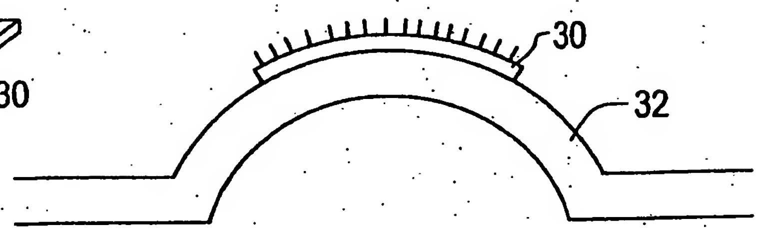

FIG. 6
PRIOR ART

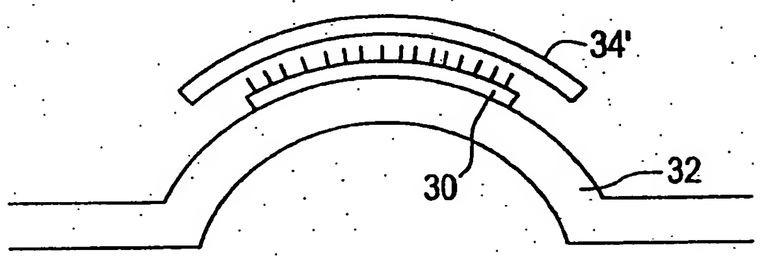

FIG. 7
PRIOR ART

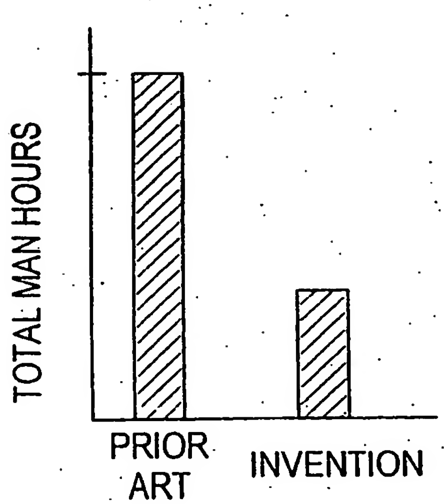

FIG. 8

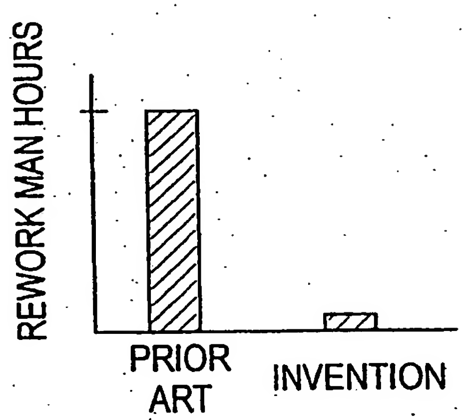

FIG. 9

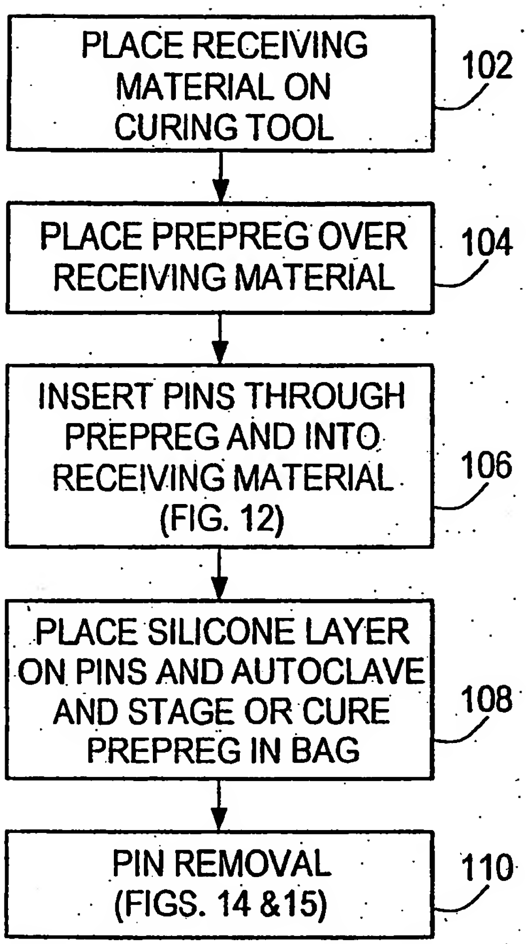

FIG. 10

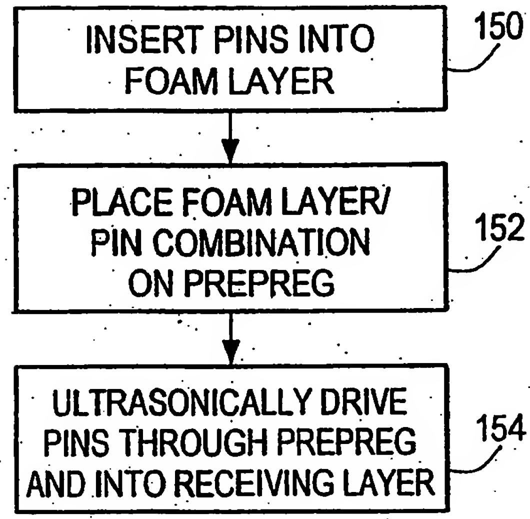

FIG. 12

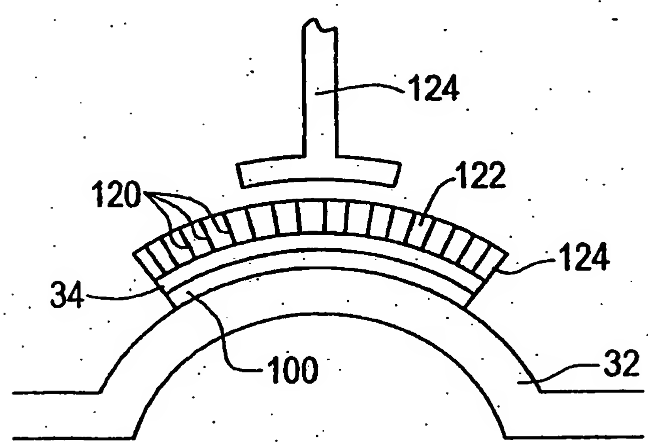

FIG. 13

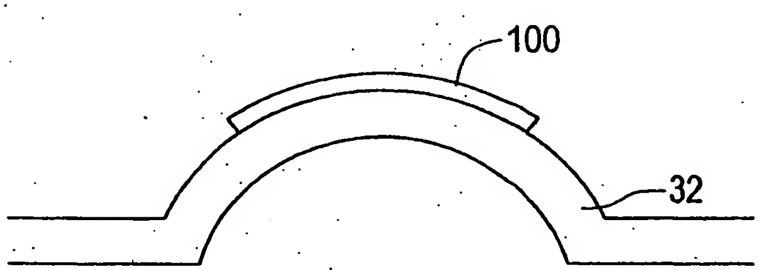

FIG. 11

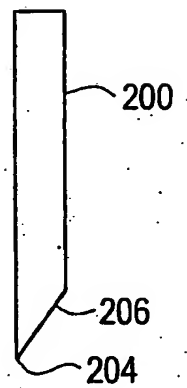

FIG. 16

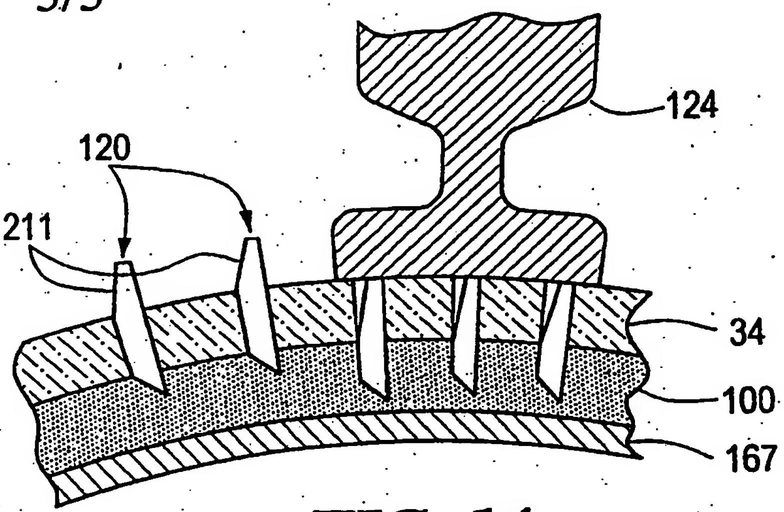

FIG. 14

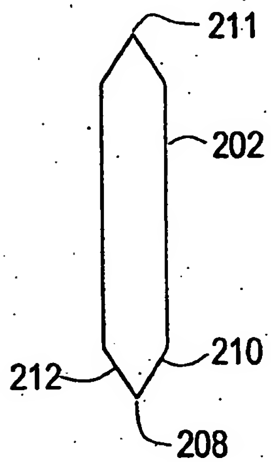

FIG. 17

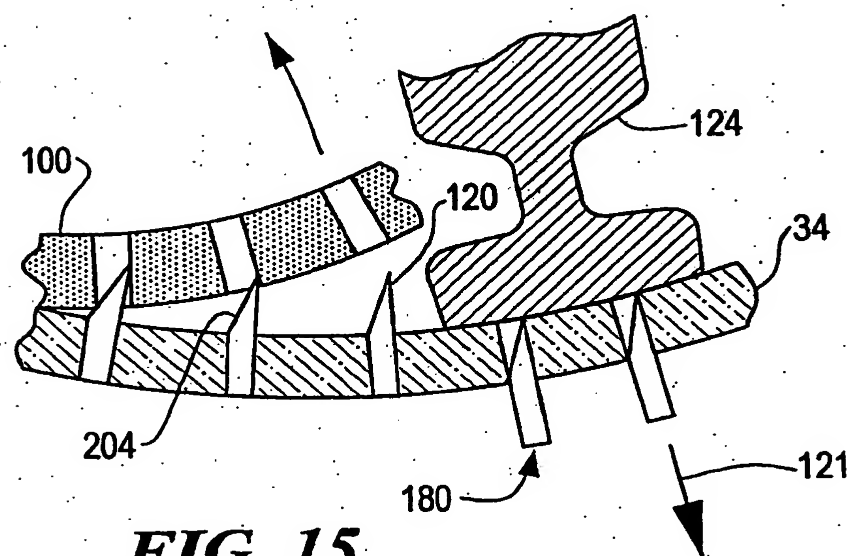

FIG. 15

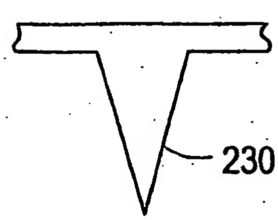

FIG. 18

PRIOR ART

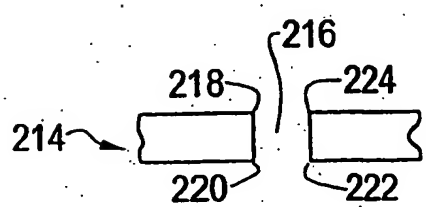

FIG. 19

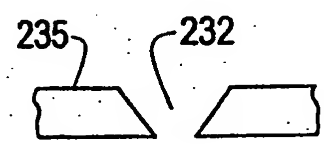

FIG. 20

PRIOR ART

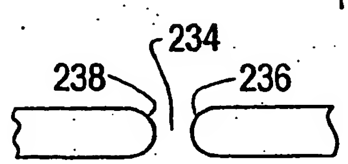

FIG. 21

PRIOR ART

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/02846

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) : B28B 1/48
US CL : 264/154, 156, 442, 443
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 264/154, 156, 442, 443

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4,160,055 A (REED) 03 July 1979 (03-07-79), see entire document.	1-2, 4-15
Y	US 5,252,279 A (GORE et al.) 12 October 1993 (12-10-93), see entire document.	1-2, 7, 13-15
Y	US 4,747,895 A (WALLERSTEIN et al.) 31 May 1988 (31-05-88), col. 4, lines 10-64.	1-2, 5-6, 13-15
Y	US 5,589,015 A (FUSCO et al.) 31 December 1996 (31-12-96), col. 2, lines 43-50.	3
Y	US 3,719,736 A (G.M. WOODRUFF) 06 March 1973 (06-03-73), col. 3, lines 10-32.	1-2, 4, 7, 10, 13-15
Y	US 2,244,550 A (F.J. CHANDLER) 03 June 1941 (03-06-41), col. 3, lines 29-44 and col. 4, lines 14-28.	1-2, 4, 7, 13-15

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:
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"O" document referring to an oral disclosure, use, exhibition or other means
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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 MARCH 1999	13 APR 1999

Name and mailing address of the ISA/US	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/02846

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3,683,736 A (LOOSE) 15 August 1972 (15-08-72).	5, 6